EFFECT OF ACIDIC LAKE WATER ON SURVIVAL OF AURORA TROUT *(SALVELINUS FONTINALIS)* EMBRYOS AND ALEVINS

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ABSTRACT

During the 1960's the aurora trout, a rare colour variant of the brook trout (Salvelinus fontinalis), disappeared from its native waters in northeastern Ontario. Its disappearance has been attributed to acidification of these waters by atmospheric deposition of industrial emissions from metal smelters at Sudbury, Ontario. Recently, water quality in the Sudbury area has improved due to emission reductions. Our experiments were designed to assess the toxicity of current water quality in the native lakes of aurora trout.

During May 1984, hatchery-reared aurora trout alevins were held for 4 days in three of their native lakes, Whirligig, Whitepine and Wilderness (pH 4.5 -4.8), and a control lake, Regan Lake (pH 6.5). Survival was low in the native lakes (18.2% to 32.5%). Survivors of the bioassay were released into Whirligig Lake and a few of these survived for at least 3 years. During their first year in the lake they exhibited exceptionally rapid growth (Age 2 mean fork length 33.5 cm). No successful spawning was observed and no adults appeared to survive past 1987 (age 3+).

In a second bioassay, embryos and alevins were buried in the substrate at three groundwater upwelling sites. Two of the sites developed low dissolved oxygen (2.1 - 2.4 mg/l) and survival was 0%. At the remaining site, survival was high in the low acidity (pH 5.4) groundwater (86.6% to hatch; 98.5% as free embryos; 85.2% total) relative to survival in low pH (4.9) ambient lake water (45.6% to hatch; 41.2% as free embryos; 18.7% total). During a 14 day exposure of groundwater-reared fish to ambient conditions, alevins experienced no mortality. Studies of aurora trout survival and reproduction are continuing; however, it appears that current water quality is unsuitable for reintroduction of aurora trout in their native waters.

INTRODUCTION

Three small (4.1-77.8 ha) high elevation (434-480 m) lakes in northeastern Ontario, near Temagami (Table 1 and Fig. 1.), historically supported native populations of aurora trout, a rare colour variant of the brook trout (Salvelinus fontinalis). The aurora trout was originally classified by Henn and Rickenbach (1925) as a distinct species, Salvelinus timagamiensis, but more recently workers have recognized its close relationship to the brook trout (P. Ihssen, personal communication). Sale (1967) considered the differences in colouration, epidermal thickness and behaviour sufficient to argue for subspecies status (Salvelinus fontinalis timagamiensis). Compared to brook trout, aurora trout lack the yellow spots and vermiculations and have a thicker epidermis (2X) with more mucous glands (Fig. 2).

Aurora trout disappeared from their native lakes in the 1960's, presumably due to the acidification of these waters by atmospheric emissions from the metal smelters in Sudbury, located 100 km southwest of the aurora trout lakes (Keller 1978). In 1961, 3000 eggs were collected from Whitepine and Whirligig Lakes and transferred to Hill's Lake hatchery (P. Graf, hatchery manager, personal communication). The stock was maintained at Hills Lake hatchery through to the late 1970's and since then at North Bay hatchery.

Figure 1. - Locations of three aurora lakes near Sudbury, Ontario.

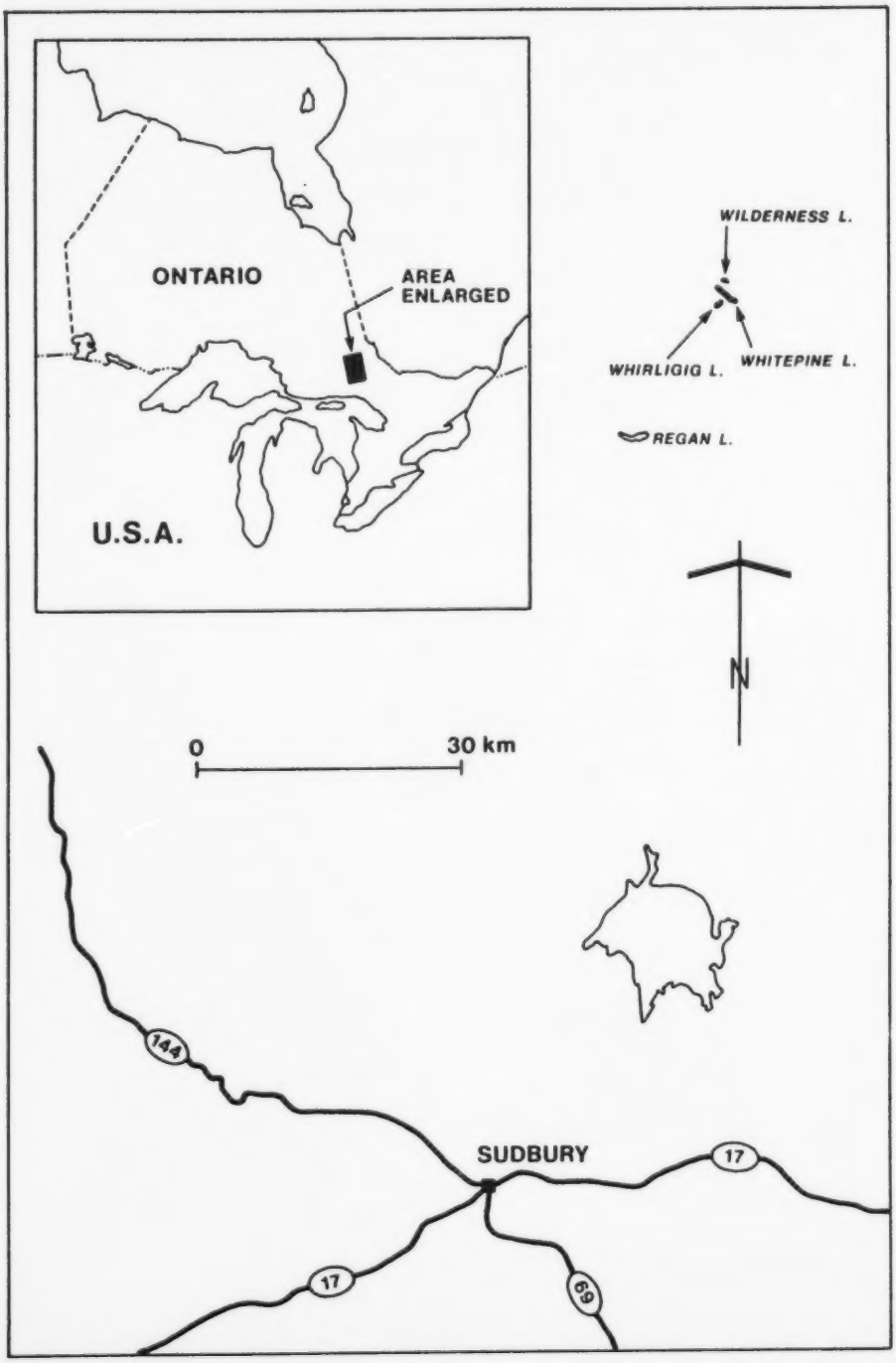

Figure 2. - Male aurora trout in Whirligig Lake, September 1987, a survivor of young-of-year released in May 1984. An ultrasonic tag has been attached to track the movements of the fish. Note the lack of spots and vermiculations as compared to those of a typical brook trout.

TABLE 1. - Morphological and chemical characteristics of aurora trout lakes near Sudbury, Ontario. Chemical data are from Keller (1978). Samples collected 1 m below lake surface in August, 1976.

	Whitepine	Whirligig	Wilderness
Latitude (N)	47°23'00''	47°22'40''	47°23'54''
Longitude (W)	80°38'00''	80°38'15''	80°38'15''
Altitude (m)	434	435	480
Surface area (ha)	77.7	11.4	4.1
Maximum depth (m)	21.3	11.0	9.1
Mean depth (m)	7.0	4.7	5.7
Volume (10^4 m^3)	591.7	54.0	23.0
Secchi depth (m)	6.8 - 7.7	4.0 - 5.5	8.0
pH	4.7	4.8	4.5
Alkalinity (mg/l as $CaCO_3$)	0.8	0.8	1.0

Since the extirpation of the aurora trout from its native waters, attempts have been made to establish the stock in other lakes. In the 1960's, plantings of fingerlings were conducted in Seahorse Lake and Reed Lake, both near the town of Kirkland Lake, but those stockings failed to establish naturally reproducing populations. A non-reproducing brood stock population in Alexander Lake, near Kirkland Lake, has been maintained with plantings of 10,000 yearlings every two years. Two plantings in one of the native lakes, Whitepine Lake (pH 5.3

in 1971), 2600 "swim-up" fry in 1969 and 2500 fingerlings in 1970, were unsuccessful (Ontario Ministry of Natural Resources - Kirkland Lake District files).

Recently, water quality of lakes in the Sudbury area has improved due to local reductions in industrial emissions (Keller et al 1986) and some of lakes may now be suitable for reintroduction of extirpated fish species. We conducted field experiments to assess the suitability of current water quality in the native aurora trout lakes for reintroduction of this unique strain of brook trout. In situ bioassays were used to assess the toxicity of both surface water and upwelling groundwater. Groundwater was tested because brook trout usually spawn in groundwater seepage areas (Webster and Eiriksdottir 1976).

METHODS

MAY 1984 HOLDING EXPERIMENT

Aurora trout alevins (as defined by Balon 1980) (mean total length = 29 mm) were obtained from the Ontario Ministry of Natural Resources North Bay hatchery on May 11, 1984. Thirty randomly selected alevins were placed in each of 20 screened - 1 L plastic containers. All fish were transported to the control site at Regan Lake (pH 6.53) where hatchery water was exchanged for low conductivity lake water. This acclimation procedure was intended to reduce the immediate shock of

transfer to the low pH and low conductivity water in the aurora lakes. The fish were in Regan Lake water for 1 - 1.5 hr before being placed in the test lakes.

Five holding pens were installed in each study lake (Wilderness, Whirligig, Whitepine and Regan). Pens were anchored in 4 - 6 m of water and suspended 2 m below a surface float. Four days later the pens were removed and the live and dead fish were counted. All survivors (n = 260) and 2400 surplus alevins were released into Whirligig Lake.

Water samples (surface grab) were taken from each lake at the start (May 11) and at the end of the holding period (May 15). On each sampling occasion, water temperature and dissolved oxygen concentration were measured using a YSI model 51B dissolved oxygen meter. Thermographs (Ryan model J) anchored at the level of the holding pens provided a continuous temperature record for Wilderness and Whirligig lakes.

1985 INCUBATION EXPERIMENT in WHIRLIGIG LAKE

Fresh fertilized aurora trout eggs, obtained from brood stock held in Alexander Lake (latitude 48°17', longitude 80°35') were flown to Whirligig Lake on October 30, 1985. The eggs were placed in incubator trays (Fig. 3) which were placed in perforated plastic pails that were buried at three groundwater upwelling sites (Fig. 4). The groundwater sites were discovered during a survey in 1984. In addition, eggs were placed at an ambient (non-groundwater) site located offshore.

At each site, a plastic pail (11 L), with multiple perforations (1.25 cm diameter holes) around the bottom half, housed three incubator trays (Fig. 5). The ambient site pail (Fig. 6) was suspended 50 cm off bottom in 2 m of water. At two groundwater sites (#2 and #3), pails were buried in the substrate so that 4 - 9 cm of the pail height was still visible above the substrate. At groundwater site #1, the presence of a thick mat of vegetation and detritus necessitated a modification to the installation procedure. A large (90 L) plastic container (perforated on the bottom) was first buried in the clay substrate and then a smaller pail was suspended inside so that inlet perforations on the smaller pail would not become clogged. Within pails, incubator trays were arranged so that water flowed freely over them (Fig. 5). All groundwater pails were buried October 18. Upwelling flows (Table 2) were determined on October 20 and 29 by attaching a plastic bag to the outlet tube of each pail and measuring the amount of water collected over a period of 10 to 30 minutes. Upwelling velocity was calculated as follows: Velocity = Volume of water collected (cm^3) / time (hr) / pail cross-sectional area (cm^2).

Inspections were conducted in mid-February and, weather permitting, weekly from mid-March to the end of April. During each visit, water samples were collected, measurements made of dissolved oxygen and temperature, and the number of dead embryos in each incubator recorded. The final inspection and removal of incubators occurred on April 30 when the lake was free of ice.

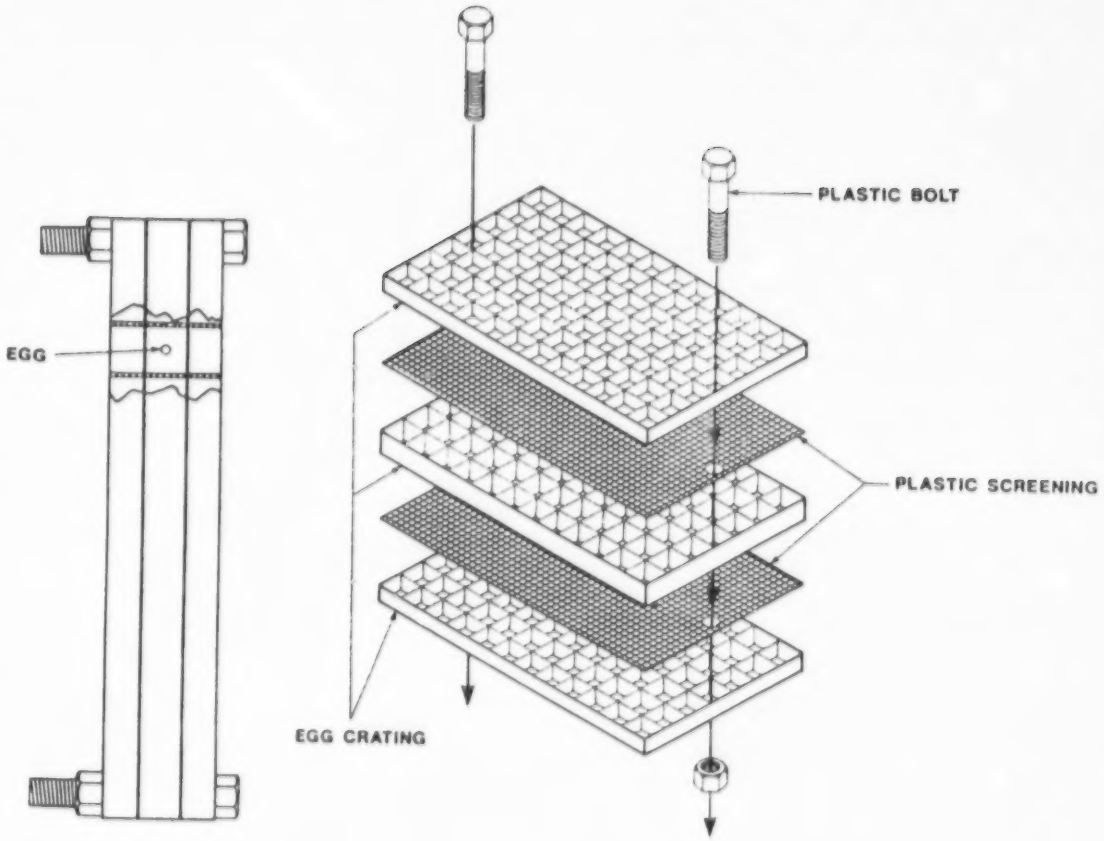

Figure 3. - Contruction details for egg incubators used in Whirligig Lake. Measurements for each section of plastic "egg crating": 17.5 X 10 X 1 (length X width X depth, in cm).

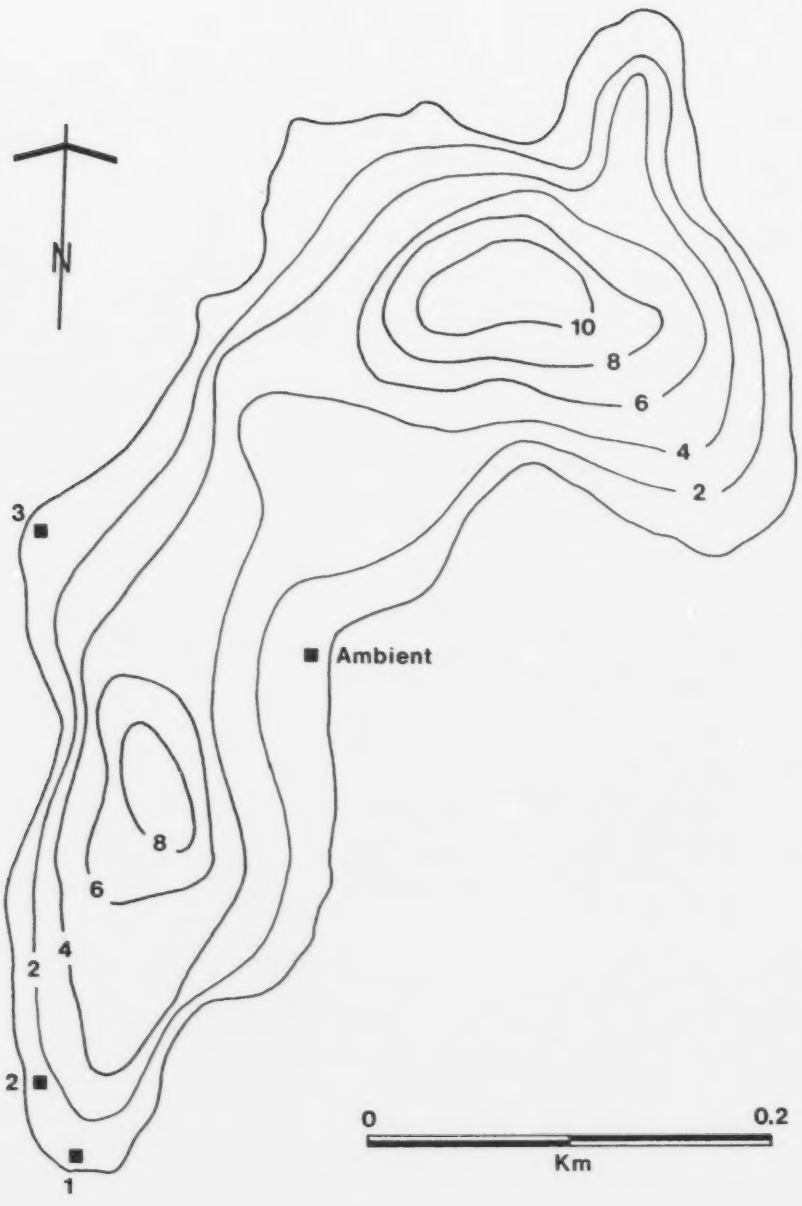

Figure 4. - Locations of groundwater upwelling sites (numbered) and ambient reference site used for incubation of aurora trout eggs in Whirligig Lake. Contours in metres.

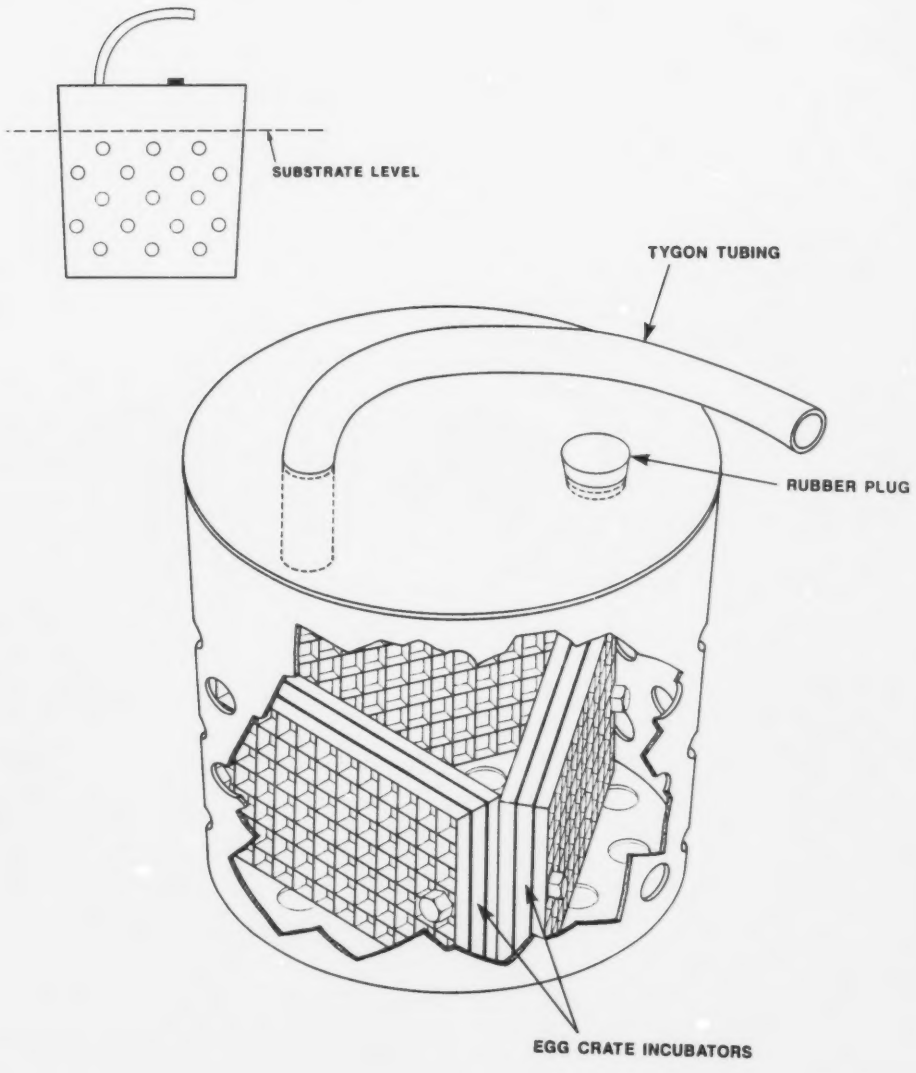

Figure 5. - Installation details for incubator pails at groundwater upwelling sites #2 and #3. The tygon tube (outside diameter 2.5 cm) was left open to provide for free flow of groundwater. The rubber plug was removed for dissolved oxygen and temperature measurements.

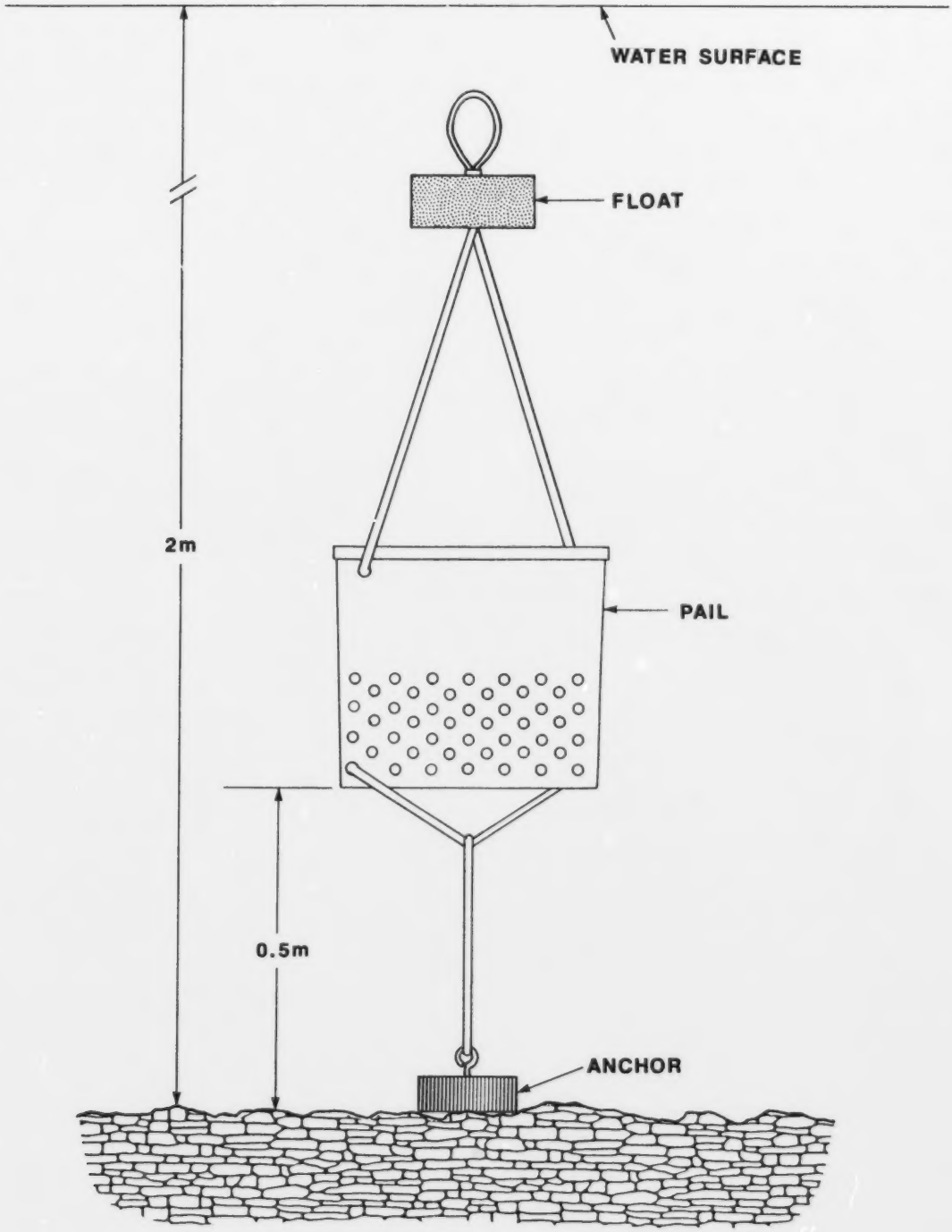

Figure 6. - Apparatus used to test survival in the ambient water of Whirligig Lake.

TABLE 2. - Physical characteristics of groundwater upwelling sites in Whirligig Lake, October 1985.

Site	1	2	3
Bottom type	1 m detritus over clay	Large rocks (4-30 cm)	Logs and silt over clay
Water depth (cm)	50	59	68
Distance from shore (m)	5.30	2.38	1.10
Mean seepage velocity (cm/hr)	1.15 (n=2)	1.21 (n=2)	0.96 (n=1)

Groundwater samples (2 L) were collected by connecting a peristaltic pump (pump discharge <1 l/min.) to the outlet tube of each pail. Ambient site samples were obtained from beside the suspended pail. Dissolved oxygen and water temperature were measured with a YSI model 57 dissolved oxygen meter. At groundwater sites #2 and #3 the probe was lowered through a hole in the pail lid which was usually kept plugged. At groundwater site #1 the probe was lowered through a hole in the outer container and measurements made adjacent to the incubator pail. Ambient measurements were taken in the water column immediately beside the incubator pail.

One hundred fish incubated at groundwater site #2 were used in a test of survival under conditions that simulated emergence into acid surface waters. Tests were also conducted using limestone treated control water. Ten 22.5 L perforated (1.25 cm diameter holes) plastic pails (Fig. 7) filled with substrate (5 with 2 - 7 cm diameter

limestone; 5 with 2 - 7 cm diameter non-calcareous gravel) were set in water 30 - 35 cm deep adjacent to shore at the ambient site. Within the large pails, smaller (2.5 L) perforated (1.25 cm diameter) plastic pails were imbedded in the substrate. Holding pens constructed from 500 ml plastic containers with plastic screen bottoms and styrofoam collars floated freely inside the small inner pail. Each holding pen received ten fish, for a total of 50 fish per treatment (5 pails of limestone and 5 pails of non-calcareous granitic gravel). During transport from groundwater site #2 to the open water site all fish were held in untreated lake water for 0.5 hours.

The bioassay ran 14 days, beginning on April 30, 1985. Three separate inspections were conducted: 2 days, 7 days and 14 days after installation. During each visit, dead fish were enumerated and removed. Water samples were collected with a peristaltic pump from the open water site and the inner container of one pail from each treatment. Dissolved oxygen and temperature in the holding pens were measured using a YSI model 57 dissolved oxygen meter.

Water samples were collected in 500 ml polystyrene bottles and, for dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) samples, in air-tight glass bottles. Containers were rinsed at least twice with sample water. Samples were kept cool and in the dark until analysis. Samples for metal analysis were acidified with 1 ml of concentrated nitric acid. Total inflection point alkalinity (TIA), conductivity and pH analyses were done at the Ministry of the

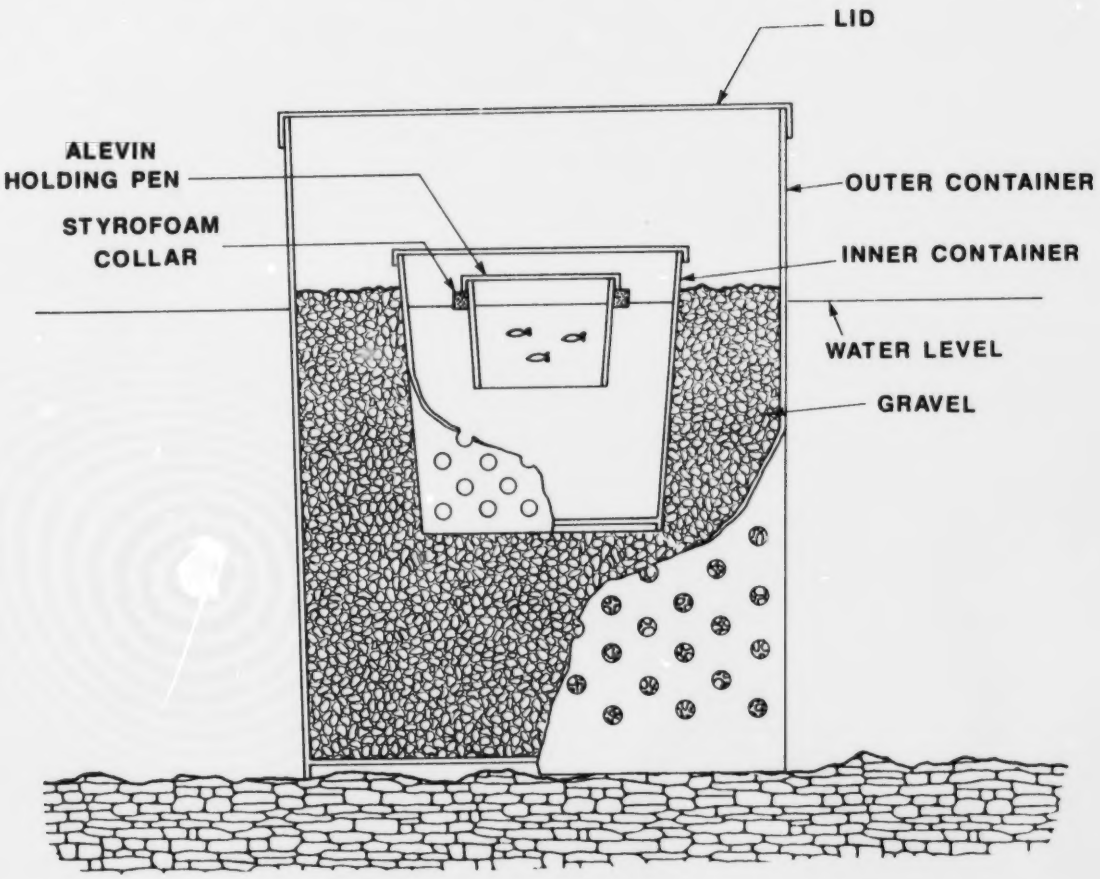

Figure 7. - Installation details for aurora trout alevin holding pens. Container volumes: outer - 22.5 L, inner - 2.5 L, alevin holding pen - 0.5 L.

Environment laboratory in Sudbury and analyses for metals, major ions, colour, DIC and DOC were done at the Ministry of the Environment laboratories in Toronto. Analyses followed methods outlined by Ontario Ministry of the Environment (1981).

LONG TERM SURVIVAL

A combination of trapnetting, gillnetting and angling was used in 1988 to assess long term survival of re-introduced aurora trout in Whirligig Lake.

STATISTICAL ANALYSIS

Statistically significant differences ($p < .05$) between means of physicochemical values were identified using the Wilcoxon 2-sample test or the Kruskal-Wallis test.

RESULTS

1984 HOLDING EXPERIMENT

WATER CHEMISTRY

The aurora lakes had low pH (4.48 - 4.78), low alkalinity (-1.3 to -0.61 mg/l), and high total aluminum levels (0.185 - 0.250 mg/l) (Table 3) relative to the control lake, Regan (pH 6.5; alkalinity 3.3 mg/l; total Al 0.024 mg/l). Dissolved oxygen levels did not differ significantly between lakes, but water temperatures were higher in Wilderness and Whirligig lakes (9.0 - 9.8 °C) than in Whitepine and Regan lakes (7.0 °C).

SURVIVAL

Survival was high in Regan Lake (98%) and low (18.2 - 32.5%) in the three aurora lakes. Within the aurora lakes there was a trend for survival to decrease with decreasing pH and increasing Al levels (Table 3). Following the exposure period, alevins held in Regan Lake were active and had vivid colouration and dark red gills. Surviving alevins in the aurora lakes were lethargic with less distinct colouration and pale coloured gills.

TABLE 3. - Summary of aurora trout alevin survival (%) and physicochemical characteristics of the holding pen sites during holding experiment, May 11-15, 1984. (n = 2 for means of physicochemical values except temperature for Wilderness Lake and Whirligig Lake which are the mean of thermograph readings at 1200 hours (n = 4)).

Lake	% Survival (95% C.I.)	pH	Alkalinity (mg/l as $CaCO_3$)	Total Al (mg/l)	Temp. (°C)	Dissolved Oxygen (mg/l)
Wilderness	18.2 (10.1)	4.484	-1.30	.250	9.0	11.0
Whirligig	24.1 (11.5)	4.691	-0.77	.210	9.8	10.8
Whitepine	32.5 (7.8)	4.776	-0.61	.185	7.0	11.0
Regan	98.0 (3.7)	6.530	3.30	.024	7.0	11.8

Of the 2660 aurora trout (mean total length 2.9 cm; mean weight 0.196 g) released in Whirligig Lake, five were captured (mean total length 8.1 cm; mean weight 5.0 g) using plexiglass traps (modified after Trippel and Crossman 1981) in late July. The next year, in October, 1985, fish were observed surfacing. A single 15 m panel of gillnet set for 20 minutes captured 13 aurora trout which were released immediately (no lengths or weights recorded). Two mortalities were later found along the shoreline (sexually immature, fork lengths 32.7 and 34.3 cm). Subsequent annual netting assessments on Whirligig Lake confirmed that a small population remained until the fall of 1987 (nine fish observed in 1986, three in 1987). Intensive netting and angling conducted in 1988 (July, August, September) indicated that no fish from the 1984 planting survived until age 4+ and that no recruits have been produced.

1985 *In Situ* TOXICITY TEST in WHIRLIGIG LAKE

WATER CHEMISTRY

The results of the 1985 bioassay indicated that chemical conditions in the reproductive habitat (groundwater seeps) were not as severe as in the water column of Whirligig Lake. pH varied across the four incubation sites with mean values of 4.9, 5.1, 5.4 and 6.3 for the ambient site and sites 1, 2 and 3, respectively. Low dissolved oxygen values (2.4 and 2.1 mg/l) and zero embryo survival were recorded at sites 1 and 3 on February 13; therefore, data from these sites are eliminated from further discussion.

Groundwater at site #2 had higher pH and alkalinity, elevated major ion levels and lower metal concentrations than the surface water (Table 4). Total Al levels were substantially higher in the ambient water from October 29 to March 24, but from April 1 to April 28 the values for both sites were comparable (Table 5). Elevated colour and DOC values indicate higher humic content in the open water. Dissolved oxygen levels at both sites ranged from 8.1 mg/l to 13.2 mg/l. Water temperatures were generally higher in the groundwater than in the lake water (Table 6).

TABLE 4. - Water chemistry (mean values) for groundwater site #2 and ambient site in Whirligig Lake for the period October 29, 1985 - April 28, 1986. Significance probability (p) of Wilcoxon 2-sample test indicated. Significant comparisons ($p < .05$) are marked with an asterisk (*).

	Site						
	Seep 2			Ambient			
	$\bar{x}$	s	(n)	$\bar{x}$	s	(n)	P
pH	5.4		(8)	4.9		(8)	.0009*
Cond. (umhos)	33.8	2.2	(8)	30.5	1.5	(8)	.0082*
Alk. (mg/l)	0.85	0.51	(8)	-0.41	0.32	(8)	.0009*
Fe (mg/l)	0.014	0.014	(7)	0.090	0.028	(7)	.0021*
Mn (mg/l)	0.017	0.014	(8)	0.081	0.011	(8)	.0021*
Al (mg/l)	0.117	0.050	(8)	0.148	0.013	(8)	.70
Ca (mg/l)	2.53	0.71	(8)	2.35	0.18	(8)	.03 *
Mg (mg/l)	0.735	0.055	(8)	0.595	0.033	(8)	.0021*
Na (mg/l)	0.72	0.15	(7)	0.58	0.06	(7)	.02 *
K (mg/l)	0.573	0.037	(7)	0.386	0.031	(7)	.0021*
Cl (mg/l)	0.20	0.12	(7)	0.22	0.12	(7)	.84
SO_4 (mg/l)	9.17	2.98	(8)	9.00	0.79	(8)	.13
DOC (mg/l)	1.9	0.6	(7)	3.0	0.6	(7)	.0059*
DIC (mg/l)	1.3	0.9	(7)	0.8	0.4	(6)	.34
Colour (True)	1.8	1.3	(8)	10.4	2.7	(8)	.0021*

TABLE 5. - Total aluminum concentrations (mg/l) for groundwater site #2 and ambient lake water during egg incubation experiment in Whirligig Lake.

Date	Seep 2	Ambient
29 Oct 1985	0.071	0.130
13 Feb 1986	0.080	0.160
17 Mar 1996	0.068	0.150
24 Mar 1986	0.068	0.140
1 Apr 1986	0.140	0.130
14 Apr 1986	0.170	0.160
22 Apr 1986	0.180	0.160
28 Apr 1986	0.160	0.150

TABLE 6. - Water temperature (°C) at groundwater site #2 and lake ambient site during egg incubation experiment in Whirligig Lake.

Date	Ambient	Seep 2
30 Oct 1985	7.0	7.0
13 Feb 1986	2.0	3.1
17 Mar 1986	2.5	3.0
24 Mar 1986	2.0	2.2
1 Apr 1986	2.5	3.8
14 Apr 1986	4.5	4.6
22 Apr 1986	3.5	4.0
28 Apr 1986	5.5	3.5

TABLE 7. - Water chemistry (mean values) for alevin holding sites in Whirligig Lake, April 30 - May 14, 1986. Significance probability (p) of Kruskal-Wallis test, a test for significant differences between all three treatments, indicated. Significant comparisons ($p < .05$) are marked with an asterisk (*).

	Site (treatment)									
	Ambient			Granite			Limestone			
	$\bar{x}$	s	(n)	$\bar{x}$	s	(n)	$\bar{x}$	s	(n)	P
pH	4.7		(4)	4.7		(4)	5.6		(4)	.02*
Conductivity (umhos)	30.8	0.5	(4)	31.0	1.2	(4)	30.0	0.0	(4)	.16
Alkalinity (TIA)	-0.75	0.24	(4)	-0.72	0.15	(4)	0.97	0.35	(4)	.03*
Fe (mg/l)	0.173	0.019	(4)	0.168	0.017	(4)	0.167	0.029	(3)	.68
Mn (mg/l)	0.072	0.003	(4)	0.072	0.005	(4)	0.071	0.002	(3)	.75
Al (mg/l)	0.193	0.010	(4)	0.198	0.015	(4)	0.213	0.025	(3)	.39
Ca (mg/l)	2.34	0.24	(4)	2.13	0.10	(4)	2.50	0.09	(4)	.05
Mg (mg/l)	0.523	0.017	(4)	0.550	0.01	(4)	0.523	0.005	(4)	.05
Na (mg/l)	0.55	0.03	(4)	0.54	0.02	(4)	0.56	0.013	(4)	.26
K (mg/l)	0.350	0.019	(4)	0.350	0.02	(4)	0.373	0.026	(4)	.53
Cl (mg/l)	0.19	0.03	(4)	0.28	0.21	(4)	0.29	0.15	(4)	.48
SO_4 (mg/l)	8.46	0.20	(4)	8.47	0.19	(4)	8.46	0.17	(4)	.99
Colour (True)	16.8	1.9	(4)	16.5	1.3	(4)	19.0	1.8	(4)	.16
DOC (mg/l)	3.8	0.2	(4)	3.6	0.4	(4)	3.8	0.4	(4)	.78
DIC (mg/l)	1.1	0.3	(3)	1.0	0.7	(4)	1.6	0.3	(3)	.27

Water chemistry in the granitic (noncalcareous) substrate incubators did not differ from untreated lake water (Table 7). Limestone treated water had higher pH and alkalinity, but concentrations of most ions and metals were not significantly different ($p \geq .05$) from ambient conditions (Table 7).

HATCHING SUCCESS AND FREE EMBRYO SURVIVAL

The survival of embryos during the egg stage was markedly higher in groundwater (mean 86.6%, range 76.0 - 97.9%) than in untreated lake water (mean 45.6%, range 27.5 - 61.2%). Hatching was completed by February 13 (106 days post-fertilization) in the groundwater, but was delayed until March 24 (145 days post-fertilization) at the ambient site (Fig. 8).

Post-hatching survival of free embryos was also higher in the groundwater (mean 98.5%, range 95.3 - 100%) than in lake water (mean 41.2%, range 26.7 - 62.5%). Overall, the survival to the end of the embryo period was 85.2% in groundwater and only 18.7% in the lake water at Whirligig Lake. At the end of the experiment (April 30, 182 days post-fertilization) the embryos at the groundwater site had absorbed most of their yolk and were actively swimming after release from the incubators. In contrast, surviving fish from the ambient site retained large yolk sacs and were relatively inactive.

ALEVIN SURVIVAL AFTER REMOVAL FROM INCUBATORS

During the 14 day toxicity test, no deaths were recorded for fish held in either noncalcareous gravel or crushed limestone.

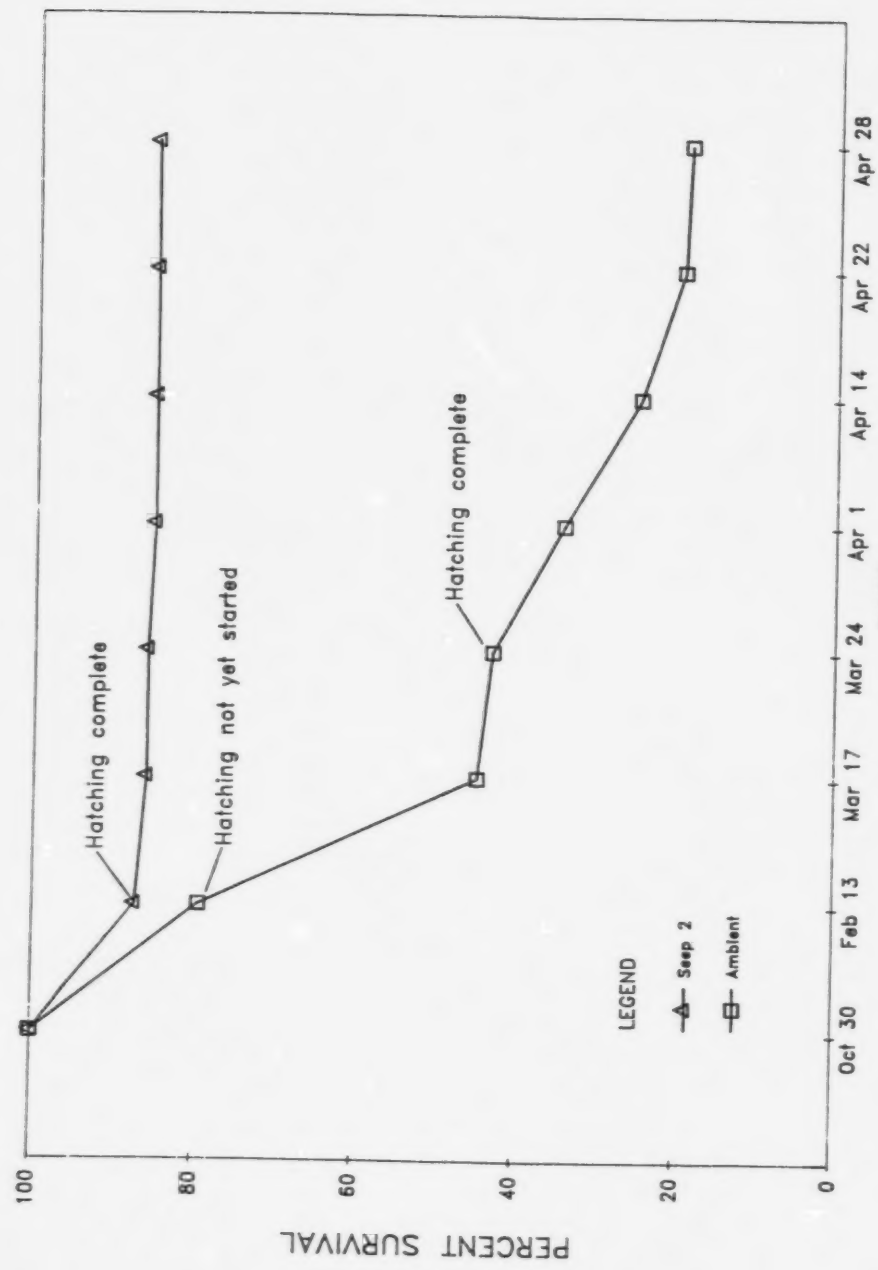

Figure 8. - Survival of aurora trout embryos at groundwater site #2 and ambient site on Whirligig Lake. October 30, 1985 - April 28, 1986.

DISCUSSION

Poor survival of aurora trout during the 1984 holding experiment and their subsequent extinction suggested that water quality in the native lakes was still unsuitable for reintroduction of this unique stock. Whirligig Lake had a pH of 4.7 - 4.9 during our study period. This is below the pH threshold ($\leq$ 5.0) for survival of brook trout determined through a netting survey of Ontario brook trout lakes (Beggs and Gunn 1986).

Growth rate of the few survivors from the 1984 stocking was rapid, with size at age 2 (fork length 32.7 - 34.3 cm) exceeding the range in mean size (total length 12.2 - 29.7 cm) reported by Carlander (1969) for age 2 brook trout from both native and introduced populations. No other fish species are resident in Whirligig Lake, therefore, the rapid growth may have been due to an abundant, unexploited food base of aquatic invertebrates. Whirligig Lake contains abundant invertebrates, particularly whirligig beetles (Gyrinidae spp.) (W. Keller, OMOE unpublished data).

Groundwater, with its higher alkalinity and pH, appears to offer some protection of embryonic stages (egg - emergence) of aurora trout (or brook trout) from the toxic effects of acidic surface waters (Gunn 1986). High survival of embryos within the substrate at seep site #2 is our evidence to suggest that whole lake water quality, rather than chemical conditions during egg incubation, is responsible for the

extinction of aurora trout from these lakes. Ground water appears to have an ameliorating influence at this site, as it does elsewhere (Norton 1982, Curry 1988).

Low dissolved oxygen levels (2.1 - 2.4 mg/l) in the groundwater at site #1 and site #3 rendered them unsuitable for successful incubation of aurora trout eggs. Good survival for salmonid eggs has been documented in the laboratory at dissolved oxygen levels as low as 2.6 mg/l (Silver et al. 1963; Garside 1966), but lethal limits are often much higher in the field. Lacroix (1985) reported poor survival for Atlantic salmon eggs incubated in streambed gravel with dissolved oxygen levels below 6.0 mg/l. Concentrations below 4 - 5 mg/l are usually lethal to rainbow trout embryos in natural redds (Sowden and Power 1985).

The results of our toxicity tests in Whirligig Lake, indicate a greater sensitivity to acidic water than has been suggested by the laboratory studies. Good survival (>75%) of brook trout held at pH $\geq$ 4.6 from fertilization to hatch was observed by Trojnar (1977). Similarly, good survival has been observed, in combination with Al, at pH 4.1 (Baker and Schofield 1982) and 4.8 (Hutchinson et al. 1988). The discrepancy between laboratory and field results is well documented (Haines 1981) and may be due to the presence of stresses in the field which were not examined in the laboratory.

Field studies conducted in acidified lakes in Quebec and an acidic West Virginia stream produced results similar to our study in Whirligig

Lake. St-Pierre and Moreau (1987) documented >97% survival of brook trout eggs after 10 days incubation at pH 4.5, 5.2 and 6.7 (Al 70; Mn<10; Zn<10; Cu<5; Pb<15; all in ug/l). Whereas, Leclerc et al (1984) reported 70% egg survival during the first few days of development and no survival at hatch in lake water of pH 4.8 (Al 171; Mn 21; Zn 11.3; Cu 6.9; Pb 16.4; all in ug/l). In the West Virginia stream (mean pH = 5.0, range 4.7 - 5.4; mean total Al = 245 ug/l, range 5 - 460), Jordahl and Benson (1987) reported 0.4% and 0% survival, respectively, for wild and domestic strain brook trout embryos to the end of the yolk-sac stage. These results indicate that, at pH similar to the ambient site in Whirligig Lake (pH 4.9; Al 148; Mn 81; Fe 90; all in ug/l), survival tends to decrease as metal concentrations increase.

In low pH water, development of brook trout embryos is generally delayed (Hutchinson et al. 1988, Jordahl and Benson 1987, Gunn and Keller 1984, Baker and Schofield 1982, Swarts et al. 1978). Both elevated temperatures and elevated pH at groundwater site #2 may have contributed to the early hatch and advanced development at that site compared to the ambient site.

Gunn and Keller (1981) incubated eyed brook trout eggs in an acidic lake and found that only 0.1% emerged from incubators placed in non-calcareous gravel (pH 5.45: Al 167; Mn 123; Zn 29; Ni 6; Cu 4; Fe 103; all in ug/l), but that 33.6 - 64.3% emerged from incubators placed in limestone (pH 6.29: Al 178; Mn 115; Zn 29; Ni 6; Cu 5; Fe 99). Alevins held for 7 days after emergence showed 92 - 100% survival at pH 5.05 -

5.30 and pH 7.00 - 8.07. Similarly, good short term (14 d) survival (100%) was also observed for groundwater-reared aurora trout alevins in the acidic (pH 4.7) ambient water of Whirligig Lake, suggesting that the critical period for aurora trout survival is post emergence, when the fish are free swimming in the open lake. There is relatively little information on the chronic factors that affect long-term survival in acidic water.

In addition to direct mortality, the water quality of the aurora lakes may be unsuitable for various aspects of natural reproduction. Reduced viability of brook trout gametes in acidified water has been demonstrated (St-Pierre and Moreau 1987) and may adversely affect fertilization. Gametogenesis is also impaired at low pH, resulting in reductions in egg number (Mount 1973; Craig and Baksi 1977). Altered Ca metabolism in adults may also inhibit spawning in low pH lakes (Beamish et al 1975; Lockhart and Lutz 1977).

These results indicate that current water quality, as of 1988, is not suitable for the reintroduction of the species.

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